#### NASA/TM-2000-209891, Vol. 200



## Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Karl Huemmrich, Editors

Volume 200 BOREAS TF-5 SSA-OJP Tower Flux and Meteorological Data

D. Baldocchi and C. Vogel

National Aeronautics and Space Administration

**Goddard Space Flight Center** Greenbelt, Maryland 20771

#### The NASA STI Program Office ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION.
   English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at http://www.sti.nasa.gov/STI-homepage.html
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at (301) 621-0134
- Telephone the NASA Access Help Desk at (301) 621-0390
- Write to:
   NASA Access Help Desk
   NASA Center for AeroSpace Information
   7121 Standard Drive

Hanover, MD 21076-1320

#### NASA/TM-2000-209891, Vol. 200



# Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Karl Huemmrich, Editors

# Volume 200 BOREAS TF-5 SSA-OJP Tower Flux and Meteorological Data

Dennis Baldocchi and Christoph Vogel National Oceanic and Atmospheric Administration/ATDD Oakridge, Tennessee

National Aeronautics and Space Administration

**Goddard Space Flight Center** Greenbelt, Maryland 20771

	Available from:	
NIAGA Conton for A G T C		Ni-diamater distribution of the control of the cont
NASA Center for AeroSpace Information		National Technical Information Service
7121 Standard Drive		5285 Port Royal Road
Hanover, MD 21076-1320		Springfield, VA 22161
Drice Code: A17		Del - C 1 - A 10
Price Code: A17		Price Code: A10

#### **BOREAS TF-5 SSA-OJP Tower Flux and Meteorological Data**

Dennis Baldocchi, Christoph Vogel

#### **Summary**

The BOREAS TF-5 team collected tower flux data at the BOREAS SSA-OJP site through the growing season of 1994. The data are available in tabular ASCII files.

#### **Table of Contents**

- 1) Data Set Overview
- 2) Investigator(s)
- 3) Theory of Measurements
- 4) Equipment
- 5) Data Acquisition Methods
- 6) Observations
- 7) Data Description
- 8) Data Organization
- 9) Data Manipulations
- 10) Errors
- 11) Notes
- 12) Application of the Data Set
- 13) Future Modifications and Plans
- 14) Software
- 15) Data Access
- 16) Output Products and Availability
- 17) References
- 18) Glossary of Terms
- 19) List of Acronyms
- 20) Document Information

#### 1. Data Set Overview

#### 1.1 Data Set Identification

BOREAS TF-05 SSA-OJP Tower Flux and Meteorological Data

#### 1.2 Data Set Introduction

Eddy correlation flux measurements of sensible heat, latent heat, and CO<sub>2</sub> fluxes were made above and under the canopy of the BOReal Ecosystem-Atmosphere Study (BOREAS) Southern Study Area (SSA) Old Jack Pine (OJP) site.

#### 1.3 Objective/Purpose

The objective was to measure and model air-surface exchange rates of water vapor, sensible heat, and CO<sub>2</sub> over and under a boreal forest and to study the abiotic and biotic factors that control the fluxes of scalars in this landscape. Scalar flux densities were measured with tower-mounted measurement systems. Tower-mounted flux measurement systems were installed above and below an old jack pine forest canopy, which allowed investigation of the relative roles of vegetation and the forest floor on the net canopy exchange of mass and energy. The tower-mounted flux measurement system was also used to study temporal patterns (diurnal and seasonal) of mass and energy exchange at a point in the landscape.

#### 1.4 Summary of Parameters

Key measured flux variables were net radiation, Photosynthetic Photon Flux Density (PPFD), latent heat, sensible heat, soil heat, and CO<sub>2</sub> flux densities above and below the canopy. Key measured meteorological variables included wind speed, wind direction, air temperature, relative humidity, soil temperature, CO<sub>2</sub> concentration, and ozone concentration.

#### 1.5 Discussion

Eddy flux densities of CO<sub>2</sub>, water vapor, and sensible heat and turbulence statistics were measured above and below the OJP (Pinus banksiana) site near Nipawin (53.92 °N, 104.69 °W), Saskatchewan, Canada. The site was relatively level and the forest stand was horizontally homogeneous throughout the area deemed as the flux footprint, a region extending over 1 km upwind.

One eddy flux measurement system was mounted at 20 m above the ground. This system was about 5 to 10 m above the canopy and was mounted on the double scaffold tower provided by the BOREAS project. The sensors on a boom extended 3 m upwind of the tower, to minimize flow distortion. The azimuth angle of the boom was altered to place the instrument array into the wind. The subcanopy flux system was mounted 2 m above the ground on a portable telescoping tower, supplied by National Oceanic and Atmospheric Administration/Atmospheric Turbulence and Diffusion Division (NOAA/ATDD). This lower tower was placed 30 to 50 m away from the base of the main tower to avoid interference from local foot traffic. This dual flux measurement method has been successfully developed and used in a deciduous forest (Verma et al., 1986; Baldocchi et al., 1987; Baldocchi and Meyers, 1991). By analogy, the investigators feel that the dual measurement approach can be used with confidence above and below the jack pine stand.

The eddy flux densities were determined by calculating the covariance between vertical velocity and scalar fluctuations (see Baldocchi et al., 1988). Wind velocity and virtual temperature fluctuations were measured with identical 3-D sonic anemometers. Experience has shown that it is prudent to use 3-D sonic anemometers in forest meteorology applications. When deploying an anemometer over a forest, it is nearly impossible to physically align the vertical velocity sensor normal to the mean wind streamlines; sensor orientation problems typically arise because of sloping terrain and the practice of extending a long boom upwind from a tower. The use of a 3-D anemometer allows numerical coordinate rotations to be made to align the vertical velocity measurement normal to the mean wind streamlines. CO<sub>2</sub> and water vapor fluctuations were measured with an open-path, infrared absorption gas analyzer, developed at NOAA/ATDD (Auble and Meyers, 1992).

Fast-response meteorology data were digitized, processed, and stored using a microcomputer-controlled system and in-house software. Digitization of sensor signals was performed with hardware on the sonic anemometer. Sensor data were output at 10 Hz. Spectra and cospectra computations showed that these sampling rates were adequate for measuring fluxes above and below forest canopies (Baldocchi and Meyers, 1991; Amiro, 1990). Scalar fluctuations were computed, real-time, using a running mean removal method (McMillen, 1988). Analytical and numerical tests showed the recursive filter time constant of 400 s yielded fluxes similar to those computed with the conventional Reynolds averaging approach. Mass and energy flux covariances were stored at half-hour intervals on high-capacity Bernoulli removable disk media. Instantaneous data were recorded periodically.

Proper interpretation of experimental results and model evaluation requires detailed ancillary measurements of many environmental variables. Energy balance components that were measured include the net radiation balance, soil heat flux, and canopy heat storage.

#### 1.6 Related Data Sets

BOREAS TF-04 SSA-YJP Tower Flux, Meteorological, and Canopy Condition Data

BOREAS TF-08 NSA-OJP Tower Flux Data

BOREAS TF-09 SSA-OBS Tower Flux, Meteorological, and Soil Temperature Data

BOREAS TF-11 SSA-Fen Tower Flux and Meteorological Data

BOREAS AFM-07 SRC Surface Meteorological and Radiation Data

BOREAS TE-06 Allometry Data

BOREAS TGB-10 Oxidant Concentration Data over the SSA

BOREAS TGB-10 Oxidant Flux Data over the SSA

#### 2. Investigator(s)

#### 2.1 Investigator(s) Name and Title

Dr. Dennis Baldocchi and Dr. Christoph Vogel NOAA/ATDD

#### 2.2 Title of Investigation

Experimental and Modeling Studies of Water Vapor, Sensible Heat, and CO<sub>2</sub> Exchange Over and Under a Boreal Forest

#### 2.3 Contact Information

#### Contact 1:

Dennis Baldocchi NOAA/ATDD P.O. Box 2456 Oak Ridge, TN 37831 (423) 576-1243 (423) 576-1327 (fax) baldocchi@atdd.noaa.gov

#### Contact 2:

Christoph Vogel NOAA/ATDD P.O. Box 2456 Oak Ridge, TN 37831 (423) 576-1243 (423) 576-1327 (fax)

#### Contact 3:

Karl F. Huemmrich University of Maryland NASA GSFC Code 923 Greenbelt, MD 20771 (301) 286-4862 (301) 286-0239 (fax) Karl.Huemmrich@gsfc.nasa.gov

#### 3. Theory of Measurements

#### **Micrometeorological Measurement Theory:**

Micrometeorological methods allow one to measure short-term flux densities (moles per unit area and time) of scalar compounds to and from forest ecosystems. The equation describing the conservation of mass provides the basic framework for applying micrometeorological methods to measure the vertical flux density of S (F) between the surface and the atmosphere. The conservation equation describes the factors that control the time rate of change of a scalar mixing ratio in a controlled volume. To grasp an understanding of this relationship, the factors controlling the water level in a bath tub must first be considered. The water level will remain the same if the amount of water flowing into the tub equals that removed through the drain. In the atmosphere, for example, the concentration of a sulfur compound will remain unchanged if the mean and turbulent fluxes entering a controlled volume equal those leaving (the flux divergence is zero). On the other hand, concentrations will vary with time if the flux of sulfur entering the system differs from that leaving, as when plume impaction occurs.

How can the conservation equation be applied to measure fluxes? In the field, fluxes are measured at a given height above the surface, but the variable to be determined is the rate CO<sub>2</sub> is taken up by the surface below. The vertical flux density of S will remain unchanged with height if the underlying surface is 1) homogeneous and extends upwind for a considerable distance (this requirement ensures the development of a surface boundary layer); 2) if scalar concentrations are steady with time; and 3) if no chemical reactions are occurring between the surface and the measurement height.

Condition 1 can be met easily through proper site selection. As a rule of thumb, the site should be flat and horizontally homogeneous for a distance between 75 and 100 times the measurement height (Monteith and Unsworth, 1990). Condition 2 is met often for many scalars. Nonsteady conditions are most apt to occur during abrupt transitions between unstable and stable atmospheric thermal stratification, during the passage of a front, or from the impaction of a plume from nearby power plants.

#### **Eddy Correlation Technique:**

The eddy correlation method is a direct method for measuring flux densities of scalar compounds. The vertical flux density is proportional to the covariance between vertical wind velocity (w) and scalar concentration fluctuations (c).

A wide range of turbulent eddies contributes to the turbulent transfer of material. Proper implementation requires sampling across this spectrum of eddies. In frequency domain, eddies contributing to turbulent transfer having periods between 0.5 and 2000 seconds typically contribute to mass and energy exchange (Wesely et al., 1989). Hence, wind and chemical instrumentation must be capable of responding to high-frequency fluctuations. Computer-controlled data acquisition systems must sample the instrumentation frequently to avoid aliasing and average the signals over a sufficiently long period to capture all the contributions to the transfer.

On applying the covariance relation, it is assumed implicitly that the mean vertical flux density is perpendicular to the streamlines of the mean horizontal wind flow. Consequently, the mean vertical velocity, perpendicular to the streamlines of the mean wind flow, equals zero. In practice, nonzero vertical velocities occur because of instrument misalignment, sloping terrain, and density fluctuations. These effects must be removed when processing the data; otherwise, mean mass flow can introduced a bias error (see Businger, 1986; Baldocchi et al., 1988).

Evaluating the accuracy of the eddy correlation method is complicated. Factors contributing to instrument errors include time response of the sensor, signal-to-noise ratio, sensor separation distance, height of the measurement, and signal attenuation caused by path averaging and sampling through a tube. Natural variability is caused by nonsteady conditions and surface inhomogeneities. Under ideal conditions, natural variability exceeds about +/-10%, so it is desirable to design a system with an error approaching this metric.

Moore (1986) discusses transfer functions for sensor response time and separation distance. Preliminary calculations of transfer function integrals were performed. Corrections because of sensor time constants and separation are less than a few percent. Hence, it was decided not to make transfer function to the flux measurements; the experimental design minimized the need for such corrections since an open-path infrared gas analyzer (IRGA) and a sonic anemometer were used. Furthermore, these instruments were placed over a tall rough forest, so small distances in physical displacement have little impact on the measurement of scalar flux densities.

#### 4. Equipment

#### 4.1 Sensor/Instrument Description

#### 4.1.1 Collection Environment

Measurements were collected continuously through the growing season of 1994. The tower extended above the canopy and was exposed to direct sunlight and weather. The site operated only during the growing season; consequently, the temperatures were mild, and freezing conditions were not encountered.

#### 4.1.2 Source/Platform

Above-canopy measurements were made from a 26-meter double-scaffold walk-up tower. The subcanopy flux system was mounted 2 m above the ground on a portable telescoping tower. This lower tower was placed 30 to 50 m away from the base of the main tower to avoid interference from local foot traffic.

Eddy correlation flux measurements were made using a triple-axis Applied Technology, Inc. (ATI) sonic anemometer and an infrared absorption spectrometer. The sonic anemometer measured vertical (w) and horizontal (u,v) wind velocity and air temperature (T). This anemometer model provides digital output at a rate of 10 Hz. The infrared absorption spectrometer measured water vapor and CO<sub>2</sub> density fluctuations. The sensor responds to frequencies up to 15 Hz and has low noise and high sensitivity (20 mg/m³/volt). The sensor is rugged and experiences little drift over several weeks of continuous operation.

Soil heat flux density was measured by averaging the output of three soil heat flux plates (Radiation Energy Balance Systems (REBS) model HFT-3, Seattle, WA). They were buried 0.01 m below the surface and were randomly placed within a few meters of the flux system. Soil temperatures were measured with two multilevel thermocouple probes. Sensors were spaced logarithmically at 0.02, 0.04, 0.08, 0.16, and 0.32 m below the surface. Three thermocouples were used to measure bole temperatures. Sensors were placed about 1 cm into the bole and were azimuthally spaced around a tree at breast height. Canopy heat storage was calculated by measuring the time rate of change in bole temperature in the tree trunks.

Photosynthetically active photon flux density and the net radiation balance were measured above the forest with a quantum sensor (LI-COR model LI-190S) and a net radiometer (Swissteco Model S-1 or REBS model 6), respectively. A more detailed experimental design was implemented at the forest floor because the solar radiation field below a forest canopy is highly variable (Baldocchi and Collineau, 1994). To account for this variability, measurements of solar radiation components were made using an instrument package that traversed slowly across a 14.5-m-long track.

Air temperature and relative humidity were measured with appropriate sensors (Campbell model 207 and Vaisala model HMP-35A). Wind speed and direction were measured with a propeller wind speed/direction monitor (RM Young model 05701). Infrared canopy temperature was measured with an Everest radiation thermometer (model 112C). The sensor was pointed south and oriented at 45 degrees. Ancillary data were acquired and logged on a Campbell CR-21x data logger. Half-hour averages were stored on a computer, to coincide with the flux measurements.

 $ext{CO}_2$  concentration profiles were measured with a LI-COR 6262 IRGA. Samples were drawn at 22, 17, 12, 6, and 2 m. During the first two Intensive Field Campaigns (IFCs), the 22- and 17-m levels were sampled exclusively between 0600 and 1800 hours, and the full profile at night. During the third IFC, the whole profile was sampled continuously. Solenoid valves were switched every 30 s. Data from the third IFC are most reliable because the system was modified to measure cell pressure and temperature in addition to  $ext{CO}_2$  concentration.

The eddy correlation flux systems were digitized on the tower using the analog-to-digital (A/D) converter of the ATI sonic anemometer. The A/D board was a 12- bit system. Digital signals for the three orthogonal wind velocity components, temperature, humidity, CO<sub>2</sub>, and ozone were transmitted to a 386 computer in the field lab. In-house software (FLUX.EXE) displayed the data in real time on screen for scrutiny and computed fluctuations from means and 30-minute flux covariances. Campbell 21-X data loggers were used to sample environmental variables. These data loggers were connected to another 386 computer via digital line and were interrogated every 30 minutes using Campbell Scientific software (TELCOM.EXE).

#### 4.1.3 Source/Platform Mission Objectives

The objective was to measure fluxes of sensible and latent heat and CO<sub>2</sub> using the eddy correlation technique, the radiation balance, and ground heat flux. Sampling, recording, and near-real-time processing of the data were done with computer-based data loggers.

#### 4.1.4 Key Variables

Carbon dioxide, solar, sensible and latent heat flux densities above the forest and ground surface, soil heat flux at the soil surface, and canopy heat storage.

#### 4.1.5 Principles of Operation

#### Sonic Anemometer:

Three-dimensional orthogonal wind velocities (u, v, and w) and virtual temperature (Tv) were measured with a sonic anemometer (ATI, model SWS-211/3K, Boulder, CO). The path length between transducers was 0.15 m. The sensor software corrected for transducer shadowing effects (see Kaimal et al., 1990). Virtual temperature heat flux was converted to sensible heat flux using algorithms described by Kaimal and Gaynor (1991) and Schotanus et al. (1983).

#### Infrared Absorption Spectrometer:

Water vapor and  $CO_2$  concentrations were measured with an open-path infrared absorption spectrometer. Details and performance characteristics of the spectrometer are discussed by Auble and Meyers (1992). In brief, the infrared beam was reflected three times between mirrors separated by 0.20 m, making an 0.80-m absorption path. The response time of the sensor was less than 0.1 s, sensor noise was less than 300  $\mu$ g/m³, and its calibration was steady (it varied +/- 3% during the course of the experiment). The sensor was calibrated periodically with three standard  $CO_2$  gases mixed in air, whose accuracy was  $\pm$  1%.

#### Soil Heat Flux Transducer:

An encapsulated thermopile yields a voltage output proportional to the temperature difference across the top and bottom surfaces. The device has been calibrated in terms of heat flux through transducer corresponding to the observed temperature difference.

#### 4.1.6 Sensor/Instrument Measurement Geometry

One eddy flux measurement system was placed at 20 m above the ground, on a double-scaffold tower provided by the BOREAS project. The instruments were mounted on a boom that extended 3 m upwind of the tower to minimize flow distortion. The boom was 7 m above the mean tree height and was positioned in the constant flux layer. The azimuth angle of the boom was altered periodically to place the instrument array into the predominant wind direction. Another eddy flux system was positioned near the floor of the canopy. The instruments were 1.8 m above the ground. This location was in the stem space of the canopy and virtually no foliage was present between the canopy floor and the measurement height.

#### 4.1.7 Manufacturer of Sensor/Instrument

Sonic anemometer: ATI 6395 Gunpark Dr. Unit E

Boulder, CO 80301

Soil heat transducer:

REBS
P.O. Box 15512
Seattle, WA 98115-0512
Elmer, NJ 08318
Radiation thermometer:
Everest Interscience Inc.
P.O. Box 3640
Fullerton, CA 92634

Net radiometer: REBS P.O. Box 15512 Seattle, WA 98115-0512 Elmer, NJ 08318

Data logging system: Campbell Scientific P.O. Box 551, Logan, UT 84321

#### 4.2 Calibration

#### 4.2.1 Specifications

The net radiometer, quantum sensors, and soil heat flux plates were calibrated by the manufacturer. A net radiometer and quantum sensor were new and were used as a transfer standard. The instruments were sent to the manufacturer after BOREAS IFC-3 for recalibration. The net radiometer calibrations did not change over the course of the experiment.

Flux and mean concentration CO<sub>2</sub> analyzers were calibrated against standard calibration gases. The gases were referenced to the Atmospheric Environment Service (AES), World Meteorological Organization (WMO) standards, and the BOREAS standard gases. The flux sensors were calibrated two to three times a week. Three reference gases were used to doublecheck linearity. The concentrations of the standard were about 322, 350, and 400 ppm. The zero and span of the LI-COR IRGAs were measured nearly every day.

The water vapor sensor was calibrated against mixed air samples and referenced to data from a chilled mirror dewpoint hygrometer. Stability of the water vapor calibration was checked in the field by comparing the instrument sensitivity to the output of a Vaisala relative humidity sensor. The relative humidity sensor was new and calibrated by the manufacturer. The output of the Vaisala relative humidity sensor was also compared against that of a redundant dewpoint hygrometer. Both sensors yielded identical humidity measurements.

- Sonic anemometer: supplied by manufacturer. 1.0 m/s/V with sonic path length 0.15 m
- Carbon dioxide: about 30 mg/m<sup>3</sup>/volt
- Water vapor density fluctuations: varies with vapor density. 2.0 g/m $^3$ /volt at 6  $^\circ$ C and 3 g/m $^3$ /volt at 14  $^\circ$ C
- Soil heat transducer: about 40 W/m²/mv
- Net radiation: 12 W m<sup>2</sup>/mv
- Quantum flux density: 180 \*mol/m<sup>2</sup>/s/mv
- Ozone: 28 ppb/volt

#### **4.2.1.1 Tolerance**

- Solar and net radiation: 1 W/m<sup>2</sup>
- Air temperature fluctuations: 0.1 K
- Vertical wind velocity fluctuations: 0.01 m/s
- Surface radiative temperature: 0.1 K

#### 4.2.2 Frequency of Calibration

The net radiometers were calibrated before and after the 1994 field campaign. The calibration coefficient did not change.

The flux sensors were calibrated two to three times a week. The zero and span of the LI-COR IRGA were measured nearly every day.

#### 4.2.3 Other Calibration Information

None.

#### 5. Data Acquisition Methods

The eddy correlation flux systems were digitized on the tower using the A/D converter of the ATI sonic anemometer. The A/D board was a 12-bit system. Digital signals for the three orthogonal wind velocity components, temperature, humidity, CO<sub>2</sub>, and ozone were transmitted to a 386 computer in the field lab. In-house software (FLUX.EXE) displayed the data in real time on screen for scrutiny and computed fluctuations from means and 30-minute flux covariances. Campbell 21-X data loggers were used to sample environmental variables. These data loggers were connected to another 386 computer via a digital line and were interrogated every 30 minutes using Campbell Scientific software (TELCOM.EXE).

#### 6. Observations

#### **6.1 Data Notes**

None available.

#### 6.2 Field Notes

None available.

#### 7. Data Description

#### 7.1 Spatial Characteristics

#### 7.1.1 Spatial Coverage

All data were collected at the BOREAS SSA-OJP site. The North American Datum of 1983 (NAD83) coordinates of the site are latitude 53.91634° N, longitude 104.69203° W, and elevation of 579 m.

#### 7.1.2 Spatial Coverage Map

Not applicable.

#### 7.1.3 Spatial Resolution

The data represent point source measurements taken at the given location. The site was relatively level, and the forest stand was horizontally homogeneous throughout the area deemed as the flux footprint, a region extending over 1 km upwind.

#### 7.1.4 Projection

Not applicable.

#### 7.1.5 Grid Description

Not applicable.

#### 7.2 Temporal Characteristics

#### 7.2.1 Temporal Coverage

The data were collected nearly continuously from 23-May to 16-Sep-1994.

#### 7.2.2 Temporal Coverage Map

All data were collected at the SSA-OJP site.

#### 7.2.3 Temporal Resolution

Data are reported at a 30-minute average.

#### 7.3 Data Characteristics

#### 7.3.1 Parameter/Variable

The parameters contained in the data files on the CD-ROM are:

Column Name \_\_\_\_\_ SITE NAME SUB SITE DATE OBS TIME OBS SENSIBLE\_HEAT\_FLUX\_ABV\_CNPY LATENT HEAT FLUX ABV CNPY NET\_RAD\_ABV\_CNPY SOIL\_HEAT\_FLUX\_1CM CO2\_FLUX\_ABV\_CNPY CO2 CONC ABV CNPY CO2 STORAGE CO2\_FLUX\_ABV\_PLUS\_STORAGE HEAT STORAGE DOWN\_PPFD\_ABV\_CNPY WIND DIR ABV CNPY WIND SPEED ABV CNPY FRICTION VEL ABV CNPY AIR\_TEMP\_ABV\_CNPY ABS HUM ABV CNPY SOIL\_TEMP\_2CM SOIL TEMP 4CM SOIL\_TEMP\_8CM SOIL\_TEMP\_16CM SOIL\_TEMP\_32CM BOLE\_TEMP\_1CM WETNESS SENSOR OZONE CONC SENSIBLE HEAT FLUX BELOW CNPY LATENT\_HEAT\_FLUX\_BELOW\_CNPY NET RAD BELOW CNPY CO2\_FLUX\_BELOW\_CNPY CO2 FLUX BELOW PLUS STORAGE CO2 CONC BELOW CNPY DOWN PPFD BELOW CNPY UP\_PPFD\_BELOW\_CNPY WIND\_DIR\_BELOW\_CNPY WIND SPEED BELOW CNPY FRICTION\_VEL\_BELOW\_CNPY AIR TEMP BELOW CNPY ABS\_HUM\_BELOW\_CNPY VAPOR\_PRESS\_DEFICIT\_BELOW\_CNPY CRTFCN\_CODE

REVISION DATE

**7.3.2 Variable Description/Definition**The descriptions of the parameters contained in the data files on the CD-ROM are:

Column Name	Description
SITE_NAME	The identifier assigned to the site by BOREAS, in the format SSS-TTT-CCCCC, where SSS identifies the portion of the study area: NSA, SSA, REG, TRN, and TTT identifies the cover type for the site, 999 if unknown, and CCCCC is the identifier for site, exactly what it means will vary with site type.
SUB_SITE	The identifier assigned to the sub-site by BOREAS, in the format GGGGG-IIIII, where GGGGG is the group associated with the sub-site instrument, e.g. HYD06 or STAFF, and IIIII is the identifier for sub-site, often this will refer to an instrument.
DATE OBS	The date on which the data were collected.
TIME OBS	The Greenwich Mean Time (GMT) of the start of the
	data collection.
SENSIBLE HEAT FLUX ABV CNPY	The sensible heat flux measured above the canopy.
LATENT_HEAT_FLUX_ABV_CNPY	The latent heat flux measured above the canopy.
NET_RAD_ABV_CNPY	The net radiation measured above the canopy.
SOIL_HEAT_FLUX_1CM	The surface soil heat flux
CO2_FLUX_ABV_CNPY	The carbon dioxide flux measured above the canopy
CO2_CONC_ABV_CNPY	The carbon dioxide concentration measured above
	the canopy.
CO2_STORAGE	The storage term of carbon dioxide under the eddy
	flux system.
CO2_FLUX_ABV_PLUS_STORAGE	The sum of the above canopy carbon dioxide flux
	and the under flux instrument storage term.
HEAT_STORAGE	The canopy heat storage.
DOWN_PPFD_ABV_CNPY	The incoming photosynthetic photon flux density
	measured above the canopy.
WIND_DIR_ABV_CNPY	The wind direction measured above the canopy.
WIND_SPEED_ABV_CNPY	The wind speed measured above the canopy.
FRICTION_VEL_ABV_CNPY	The friction velocity above the canopy.
AIR_TEMP_ABV_CNPY	The air temperature measured above the canopy.
ABS_HUM_ABV_CNPY	The absolute humidity measured above the canopy.
SOIL_TEMP_2CM	Soil temperature at 2 cm depth.
SOIL_TEMP_4CM	Soil temperature at 4 cm depth.
SOIL_TEMP_8CM	The soil temperature recorded at 8 cm in depth.
SOIL_TEMP_16CM	The soil temperature recorded at 16 cm in depth.
SOIL_TEMP_32CM	The soil temperature recorded at 32 cm in depth.
BOLE_TEMP_1CM	The average bole temperature at 1 cm depth into
	tree bole.
WETNESS_SENSOR	The output of the wetness sensor, indicates if
	the instruments were wet or dry.
OZONE_CONC	The ozone concentration.
SENSIBLE_HEAT_FLUX_BELOW_CNPY	The sensible heat flux measured below the canopy
LATENT_HEAT_FLUX_BELOW_CNPY	The latent heat flux measured below the canopy.
NET_RAD_BELOW_CNPY	The net radiation measured below the canopy.
CO2_FLUX_BELOW_CNPY	The carbon dioxide flux measured below the canopy

CO2\_FLUX\_BELOW\_PLUS\_STORAGE The sum of the below canopy carbon dioxide flux and the under flux instrument storage term. The carbon dioxide concentration measured below CO2 CONC BELOW CNPY the canopy. DOWN PPFD BELOW CNPY The downward photosynthetic photon flux density measured under the canopy. UP PPFD BELOW CNPY The upward (reflected) photosynthetic photon flux density measured under the canopy. WIND DIR BELOW CNPY The wind direction measured below the canopy. WIND SPEED BELOW CNPY The wind speed measured below the canopy. FRICTION VEL BELOW CNPY The friction velocity below the canopy. AIR\_TEMP\_BELOW\_CNPY The air temperature measured below the canopy. ABS\_HUM\_BELOW\_CNPY The absolute humidity measured below the canopy. VAPOR PRESS DEFICIT BELOW CNPY The vapor pressure deficit measured below the canopy. The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified

CRTFCN CODE

by Group), PRE (Preliminary), and CPI-??? (CPI

but questionable).

REVISION DATE The most recent date when the information in the

referenced data base table record was revised.

#### 7.3.3 Unit of Measurement

The measurement units for the parameters contained in the data files on the CD-ROM are:

Column Name	Units
SITE_NAME	[none]
SUB_SITE	[none]
DATE_OBS	[DD-MON-YY]
TIME_OBS	[HHMM GMT]
SENSIBLE_HEAT_FLUX_ABV_CNPY	[Watts][meter^-2]
LATENT_HEAT_FLUX_ABV_CNPY	[Watts][meter^-2]
NET_RAD_ABV_CNPY	[Watts][meter^-2]
SOIL_HEAT_FLUX_1CM	[Watts][meter^-2]
CO2_FLUX_ABV_CNPY	<pre>[micromoles][meter^-2][second^-1]</pre>
CO2_CONC_ABV_CNPY	[parts per million]
CO2_STORAGE	[micromoles][meter^-2][second^-1]
CO2_FLUX_ABV_PLUS_STORAGE	[micromoles][meter^-2][second^-1]
HEAT_STORAGE	[Watts][meter^-2]
DOWN_PPFD_ABV_CNPY	[micromoles][meter^-2][second^-1]
WIND_DIR_ABV_CNPY	[degrees from North]
WIND_SPEED_ABV_CNPY	[meters][second^-1]
FRICTION_VEL_ABV_CNPY	[meters][seconds^-1]
AIR_TEMP_ABV_CNPY	[degrees Celsius]
ABS_HUM_ABV_CNPY	[grams][meter^-3]
SOIL_TEMP_2CM	[degrees Celsius]
SOIL_TEMP_4CM	[degrees Celsius]
SOIL_TEMP_8CM	[degrees Celsius]
SOIL_TEMP_16CM	[degrees Celsius]
SOIL_TEMP_32CM	[degrees Celsius]
BOLE_TEMP_1CM	[degrees Celsius]
WETNESS_SENSOR	[none]
OZONE_CONC	[ppb]

SENSIBLE\_HEAT\_FLUX\_BELOW\_CNPY [Watts][meter^-2] LATENT\_HEAT\_FLUX\_BELOW\_CNPY [Watts][meter^-2] NET RAD BELOW CNPY [Watts][meter^-2] CO2\_FLUX\_BELOW\_CNPY [micromoles][meter^-2][seconds^-1] CO2 FLUX BELOW PLUS STORAGE [micromoles][meter^-2][seconds^-1] CO2\_CONC\_BELOW\_CNPY [parts per million] DOWN\_PPFD\_BELOW\_CNPY [micromoles][meter^-2][second^-1] [micromoles][meter^-2][seconds^-1] UP\_PPFD\_BELOW\_CNPY WIND\_DIR\_BELOW\_CNPY [degrees from North] WIND\_SPEED\_BELOW\_CNPY [meters][seconds^-1] FRICTION\_VEL\_BELOW\_CNPY [meters][seconds^-1] AIR\_TEMP\_BELOW\_CNPY [degrees Celsius] ABS\_HUM\_BELOW\_CNPY [grams][meter^-3] VAPOR PRESS DEFICIT BELOW CNPY [kiloPascals] [none]

CRTFCN CODE

REVISION DATE [DD-MON-YY]

#### 7.3.4 Data Source

The source of the parameter values contained in the data files on the CD-ROM are:

Column Name	Data Source
SITE_NAME	[Assigned by BORIS]
SUB_SITE	[Assigned by BORIS]
DATE_OBS	[Investigator]
TIME_OBS	[Investigator]
SENSIBLE_HEAT_FLUX_ABV_CNPY	[Sonic anemometer]
LATENT_HEAT_FLUX_ABV_CNPY	[Infrared Gas Analyzer]
NET_RAD_ABV_CNPY	[Net radiometer]
SOIL_HEAT_FLUX_1CM	[Soil heat transducer]
CO2_FLUX_ABV_CNPY	[Infrared Gas Analyzer]
CO2_CONC_ABV_CNPY	[Infrared Gas Analyzer]
CO2_STORAGE	[Infrared Gas Analyzer]
CO2_FLUX_ABV_PLUS_STORAGE	[Infrared Gas Analyzer]
HEAT_STORAGE	[Radiation thermometer]
DOWN_PPFD_ABV_CNPY	[Quantum sensor]
WIND_DIR_ABV_CNPY	[propeller wind speed/direction monitor]
WIND_SPEED_ABV_CNPY	[propeller wind speed/direction monitor]
FRICTION_VEL_ABV_CNPY	[Sonic anemometer]
AIR_TEMP_ABV_CNPY	[thermocouple]
ABS_HUM_ABV_CNPY	[Humidity sensor]
SOIL_TEMP_2CM	[thermocouple]
SOIL_TEMP_4CM	[thermocouple]
SOIL_TEMP_8CM	[thermocouple]
SOIL_TEMP_16CM	[thermocouple]
SOIL_TEMP_32CM	[thermocouple]
BOLE_TEMP_1CM	[thermocouple]
WETNESS_SENSOR	[Wetness sensor]
OZONE_CONC	[Ozone sensor]
SENSIBLE_HEAT_FLUX_BELOW_CNPY	[Sonic anemometer]
LATENT_HEAT_FLUX_BELOW_CNPY	[Infrared Gas Analyzer]
NET_RAD_BELOW_CNPY	[Net radiometer]
CO2_FLUX_BELOW_CNPY	[Infrared Gas Analyzer]
CO2_FLUX_BELOW_PLUS_STORAGE	[Infrared Gas Analyzer]

CO2\_CONC\_BELOW\_CNPY [Infrared Gas Analyzer] DOWN\_PPFD\_BELOW\_CNPY [Quantum sensor] UP PPFD BELOW CNPY [Quantum sensor] WIND\_DIR\_BELOW\_CNPY [propeller wind speed/direction monitor] WIND SPEED BELOW CNPY [propeller wind speed/direction monitor] FRICTION\_VEL\_BELOW\_CNPY [Sonic anemometer] AIR\_TEMP\_BELOW\_CNPY [thermocouple] [Humidity sensor] ABS\_HUM\_BELOW\_CNPY VAPOR\_PRESS\_DEFICIT\_BELOW\_CNPY [Humidity sensor] CRTFCN\_CODE [Assigned by BORIS] REVISION\_DATE [Assigned by BORIS]

#### 7.3.5 Data Range

The following table gives information about the parameter values found in the data files on the CD-ROM.

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SITE_NAME	SSA-OJP-FLXTR	SSA-OJP-FLXTR	None	None	None	None
SUB_SITE	9TF05-FLX01	9TF05-FLX01	None	None	None	None
DATE_OBS	23-MAY-94	16-SEP-94	None	None	None	None
TIME_OBS	0	2330	None	None	None	None
SENSIBLE_HEAT_FLUX_ ABV_CNPY	-176.1	497.5	-999	None	None	Blank
LATENT_HEAT_FLUX_ABV	48.1	567.5	-999	None	None	Blank
NET_RAD_ABV_CNPY	-76.9	728	-999	None	None	Blank
			-6999			
SOIL_HEAT_FLUX_1CM	-44.1	97.6	None	None	None	Blank
CO2_FLUX_ABV_CNPY	-16.36	12.93	-999	None	None	Blank
CO2_CONC_ABV_CNPY	325	3027.3	None	None	None	Blank
CO2_STORAGE	-11.27	11.34	-999	None	None	Blank
CO2_FLUX_ABV_PLUS_	-18.25	17.23	-999	None	None	Blank
STORAGE						
HEAT_STORAGE	-323.3	410.1	-999	None	None	Blank
DOWN_PPFD_ABV_CNPY	-1	1947	-999	None	None	Blank
WIND_DIR_ABV_CNPY	0	360	None	None	None	Blank
WIND_SPEED_ABV_CNPY	.09	173.199	None	None	None	Blank
FRICTION_VEL_ABV_ CNPY	0	22.627	-999	None	None	Blank
AIR_TEMP_ABV_CNPY	2.19	29.13	-999	None	None	Blank
ABS_HUM_ABV_CNPY	3.86	15.53	None	None	None	Blank
SOIL_TEMP_2CM	3.69	25.18	-999	None	None	Blank
SOIL_TEMP_4CM	4.14	22.75	-999	None	None	Blank
SOIL_TEMP_8CM	4.587	20.39	-999	None	None	Blank
SOIL_TEMP_16CM	3.59	18.19	-999	None	None	Blank
SOIL_TEMP_32CM	-3024	16.63	None	None	None	Blank
BOLE_TEMP_1CM	.36	34.97	None	None	None	Blank
WETNESS_SENSOR	DEW	PPT	None	None	None	Blank
OZONE_CONC	-29.08	35.41	-999	None	None	Blank
SENSIBLE_HEAT_FLUX_ BELOW_CNPY	-7896.2	7918.5	None	None	None	Blank
LATENT_HEAT_FLUX_	-24.9	476.4	-999	None	None	Blank

BELOW_CNPY						
NET_RAD_BELOW_CNPY	-265.5	241.1	-999	None	None	Blank
CO2_FLUX_BELOW_CNPY	-15.93	13.61	-999	None	None	Blank
CO2_FLUX_BELOW_PLUS_	-17.86	14.09	-999	None	None	Blank
STORAGE						
CO2_CONC_BELOW_CNPY	320	619	-999	None	None	Blank
DOWN_PPFD_BELOW_CNPY	-31	1548	-999	None	None	Blank
UP_PPFD_BELOW_CNPY	-13	346	-999	None	None	Blank
WIND_DIR_BELOW_CNPY	0	360	None	None	None	Blank
WIND_SPEED_BELOW_	.009	173.199	None	None	None	Blank
CNPY						
FRICTION_VEL_BELOW_	0	3.885	-999	None	None	Blank
CNPY						
AIR_TEMP_BELOW_CNPY	-2.5	31.44	-999	None	None	Blank
ABS_HUM_BELOW_CNPY	.22	15.01	None	None	None	Blank
VAPOR_PRESS_DEFICIT_	.5	4.59	-999	None	None	Blank
BELOW_CNPY						
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	14-MAY-98	19-JUN-98	None	None	None	None

Minimum Data Value -- The minimum value found in the column.

Maximum Data Value -- The maximum value found in the column.

Missng Data Value -- The value that indicates missing data. This is used to indicate that an attempt was made to determine the parameter value, but the attempt was unsuccessful.

Unrel Data Value -- The value that indicates unreliable data. This is used to indicate an attempt was made to determine the parameter value, but the value was deemed to be unreliable by the analysis personnel.

Below Detect Limit -- The value that indicates parameter values below the instruments detection limits. This is used to indicate that an attempt was made to determine the parameter value, but the analysis personnel determined that the parameter value was below the detection limit of the instrumentation.

Data Not Cllctd -- This value indicates that no attempt was made to determine the parameter value. This usually indicates that BORIS combined several similar but not identical data sets into the same data base table but this particular science team did not measure that parameter.

Blank -- Indicates that blank spaces are used to denote that type of value. N/A -- Indicates that the value is not applicable to the respective column. None -- Indicates that no values of that sort were found in the column.

#### 7.4 Sample Data Record

The following are wrapped versions of data record from a sample data file on the CD-ROM.

```
SITE NAME, SUB SITE, DATE OBS, TIME OBS, SENSIBLE HEAT FLUX ABV CNPY,
LATENT HEAT FLUX ABV CNPY, NET RAD ABV CNPY, SOIL HEAT FLUX 1CM, CO2 FLUX ABV CNPY,
CO2_CONC_ABV_CNPY, CO2_STORAGE, CO2_FLUX_ABV_PLUS_STORAGE, HEAT_STORAGE,
DOWN PPFD ABV CNPY, WIND DIR ABV CNPY, WIND SPEED ABV CNPY, FRICTION VEL ABV CNPY,
AIR_TEMP_ABV_CNPY, ABS_HUM_ABV_CNPY, SOIL_TEMP_2CM, SOIL_TEMP_4CM, SOIL_TEMP_8CM,
SOIL TEMP 16CM, SOIL TEMP 32CM, BOLE TEMP 1CM, WETNESS SENSOR, OZONE CONC,
SENSIBLE HEAT FLUX BELOW CNPY, LATENT HEAT FLUX BELOW CNPY, NET RAD BELOW CNPY,
CO2 FLUX BELOW CNPY, CO2 FLUX BELOW PLUS STORAGE, CO2 CONC BELOW CNPY,
DOWN_PPFD_BELOW_CNPY, UP_PPFD_BELOW_CNPY, WIND_DIR_BELOW_CNPY,
WIND_SPEED_BELOW_CNPY, FRICTION_VEL_BELOW_CNPY, AIR_TEMP_BELOW_CNP
Y, ABS HUM BELOW CNPY, VAPOR PRESS DEFICIT BELOW CNPY, CRTFCN CODE, REVISION DATE
'SSA-OJP-FLXTR', '9TF05-FLX01',01-JUL-94,0,7.1,2.6,84.3,-17.3,3.05,360.7,-4.2,
-1.16,30.3,285.0,310.0,.99,.132,8.06,7.91,8.43,,,10.76,11.17,5.23,'DRY',3.92,
,,,,,,,,,,,'CPI',12-JUN-98
'SSA-OJP-FLXTR', '9TF05-FLX01',01-JUL-94,30,5.4,22.3,37.8,-12.6,2.3,348.3,-6.11,
-3.82,50.5,226.0,288.0,.72,.119,10.22,8.26,8.84,,,10.72,11.15,6.13,'DRY',4.06,
,,,,,,,,,,,'CPI',12-JUN-98
```

#### 8. Data Organization

#### 8.1 Data Granularity

The smallest unit of data tracked by the BOREAS Information System (BORIS) was data collected at a given site on a given date.

#### 8.2 Data Format

The Compact Disk-Read-Only Memory (CD-ROM) files contain American Standard Code for Information Interchange (ASCII) numerical and character fields of varying length separated by commas. The character fields are enclosed with single apostrophe marks. There are no spaces between the fields.

Each data file on the CD-ROM has four header lines of Hyper-Text Markup Language (HTML) code at the top. When viewed with a Web browser, this code displays header information (data set title, location, date, acknowledgments, etc.) and a series of HTML links to associated data files and related data sets. Line 5 of each data file is a list of the column names, and line 6 and following lines contain the actual data.

#### 9. Data Manipulations

#### 9.1 Formulae

#### 9.1.1 Derivation Techniques and Algorithms

Sample computer code displaying processing methods:

#### Sensible Heat Flux

1) Test if flux covariances are significantly different from zero for 18000 samples

--Is wT non-zero?

```
IF TT > 0 THEN
SIGT = TT ^.5
RWT = WT / (SIGW * SIGT)
ELSE
RWT = 0
END IF
IF ABS(RWT) < .0146 THEN WT = 0
--correct virtual temperature heat flux from sonic to actual heat flux.
--We apply the formula of Kaimal and Gaynor 1991. Bound. Layer Met.
-- The Schotanus et al. 1983 BLM correction is not needed for the
--ATI sonic (-2 T u w'u'/c^2)
SPECIFIC HUMIDITY = ABSOLUTE HUMIDITY / (AIR DENSITY * 1000)
--Heat capacity of air weight by the moist and dry air contributions
CP_AIR = 1010 * AIR_DENSITY + 4182 * ABSOLUTE_HUMIDITY
SIG = ABSOLUTE_HUMIDITY/(1000 * AIR_DENSITY)
SIGTOT = ABSOLUTE HUMIDITY/1000 / (ABSOLUTE HUMIDITY/1000 + AIR DENSITY)
2) Correct the sonic derived sensible heat fluxes to the actual sensible heat flux.
--Note: WTCORR should be in the WE calculation, hence looping
--is needed between sensible and latent heat flux computations
WTGUESS = WT_SONIC
CCC = 0
NEWWE:
WTCORR = (WT_SONIC - .51 * TK * WQQ)
                                        --K m/s
IF ABS(WTCORR - WTGUESS) > .00001 THEN
CCC = CCC + 1
IF CCC > 10 THEN GOTO OUTWE
WTGUESS = WTCORR
GOTO NEWWE
END IF
OUTWE:
SENSIBLE_HEAT_FLUX = WTCORR * CP_AIR
                                        --W/m^2
Water Vapor and Latent Heat Flux Densities
1) 'Is wq covariance non-zero?
IF WW > 0 THEN
```

```
IF WW > 0 THEN
SIGW = WW ^ .5
ELSE
SIGW = 9999
END IF
IF QQ > 0 THEN
SIGQ = QQ ^ .5
```

```
RWQ = WQ / (SIGW * SIGQ)
ELSE
RWQ = 0
END IF

IF ABS(RWQ) < .0146 THEN WQ = 0
WQX = WQ COVARIANCE * H2OCAL --q/m²/s</pre>
```

2) Compute latent heat flux by considering temperature variations in the latent heat of vaporization.

```
LFUSION = 334000

LATENT_HEAT = 3149000 - 2370 * TAIR_K

IF TK < 273 THEN LATENT_HEAT = LAMBDA + LFUSION

LAMBDA = LATENT HEAT / 1000
```

3) Apply Webb et al density correction for E. Units are Ecorr (g/m<sup>2</sup>/s)

```
ECORR = (1 + \text{SIG} * 1.6077) * (\text{WQX} + \text{ABSOLUTE\_HUMIDITY} * \text{WTGUESS} / \text{TK}) --\text{factor of 1000 is needed to change ECORR from g/m³ to} --\text{kg m-3, so units cancel when divided by rhoa} WQQ = ECORR * <math>(1 - \text{SPECIFIC\_HUMIDITY}) / (1000 * (\text{AIR\_DENSITY} + \text{ABSOLUTE\_HUMIDITY}/1000)) --\text{m/s}  LATENT_HEAT_FLUX= LAMBDA * WQX --(\text{W/m}^2)
```

#### CO<sub>2</sub> Flux Densities

```
WC = WC_COVARIANCE * CO2CAL --mg/m<sup>2</sup>/s
```

1) Apply Webb et al. corrections for CO<sub>2</sub> and latent heat fluxes

```
CO2CONC = CO2_DENSITY * 8.314 * TK / (PRESS_KPA * 44.01)

NU = CO2CONC* 44.01 / (28.96 * 1000000)

SIG = ABSOLUTE_HUMIDITY / (AIR_DENSITY * 1000)

SIGTOT = (ABSOLUTE_HUMIDITY / 1000) / (AIR_DENSITY + ABSOLUTE_HUMIDITY / 1000)

TERM1 = 1.6077 * NU * LATENT_HEAT_FLUX / LAMBDA

H=SENSIBLE_HEAT_FLUX

TERM2 = (1 + SIG * 1.6077) * RHOC * H / (TK * AIR_DENSITY * 1005)

FC_CORR = WC + TERM1 + TERM2
```

#### **Canopy Heat Storage**

Define canopy biomass and representative specific heat by weighting the water and cellulose contributions.

1) define volume of vegetation as the product of canopy height and its basal area.

```
JACK PINE: height= 13.5 m; basal area=22 m<sup>2</sup>/ha
```

2) heat transfer coefficient is volume x Cp/time for 30 minutes

```
CP=4.175 \text{ MJ/M}^3/\text{C} for water CP=2.500 \text{ MJ/M}^3/\text{C} for cellulose
```

3) Computed canopy heat capacity using Gower's (TE-06) biomass data

#### a) bole contribution

```
PLANT_COEF = 19.9 --W/m<sup>2</sup>/C/s
CG1 = DELTA_BOLE_TEMPERATURE * PLANT_COEF
TBOLOLD = TBOL
```

#### b) heat storage in the air layer

```
DELTA_AIR_TEMPERATURE = TAVG - TOLD
```

#### c) branch and needle heat storage

```
CG1A = 3.9 * DELTAIR

CG2 = DELTAIR * 12.8 '20x1.15x1005/1800s

TOLD = TAVG
```

#### d) latent heat storage in air layer of canopy

```
DELTA_RHOV = RHOVAVG - RHOVOLD

CG3 = 27.1 * DELRHOV --20x2442/1800

RHOVOLD = RHOVAVG

CANOPY HEAT STORAGE = CG1 + CG1A + CG2 + CG3
```

#### 9.2 Data Processing Sequence

#### 9.2.1 Processing Steps

Flux covariances were computed in the field by the data acquisition program. Back at home, calibrations were double- and triple-checked by comparing old and new calibrations and by comparing the mean response of the scalar flux sensors against independent meteorological instruments. Tests were made for energy balance closure to ensure that the data were of reliable quality. Programs were then run to delete periods when the sensors were offline, off range, being maintained, or unreliable because of rain or instrument malfunction.

BORIS staff processed these data by:

- Reviewing the initial data files and loading them online for BOREAS team access.
- Designing relational data base tables to inventory and store the data.
- Loading the data into the relational data base tables.
- Working with the team to document the data set.
- Extracting the data into logical files.

#### 9.2.2 Processing Changes

None.

#### 9.3 Calculations

#### 9.3.1 Special Corrections/Adjustments

```
Eddy fluctuations:
```

```
CO2_DENSITY = CO2PPM * AIR_DENSITY * 44 / 29 --mg m-3
```

#### 9.3.2 Calculated Variables

None.

#### 9.4 Graphs and Plots

None.

#### 10. Errors

#### 10.1 Sources of Error

Factors contributing to instrument errors include time response of the sensor, signal-to-noise ratio, sensor separation distance, height of the measurement, and signal attenuation caused by path averaging and sampling through a tube. Natural variability is caused by nonsteady conditions and surface inhomogeneities. Under ideal conditions, natural variability exceeds about  $\pm 10\%$ .

#### 10.2 Quality Assessment

#### 10.2.1 Data Validation by Source

Surface energy balance was tested by comparing measurements of available energy against the sum of latent and sensible heat flux. Tests over the jack pine stand showed that the eddy flux system closes the surface energy balance within 12% and that this degree of closure is comparable with the state-of-the-art demonstrated in the literature.

Several independent checks have been made on components of this data set. The Vaisala humidity sensor was compared against a dewpoint hygrometer, and the comparison was excellent. The output of the net radiometer was compared against measurements made on Tim Crawford's airplane (Airborne Fluxes and Meteorology (AFM)-01). There was no bias between the measurements, suggesting that the impact of the net radiometer seeing the tower structure was small.

#### 10.2.2 Confidence Level/Accuracy Judgment

The following are the best estimates of accuracy for a single flux estimate:

```
Net radiation \pm 4 to 7% Soil heat flux \pm 10% Latent heat flux \pm 15 to 20% or \pm30 W m², whichever is larger Sensible heat flux \pm 15 to 20% or \pm30 W m², whichever is larger
```

None of these estimates addresses the variability of flux estimates from site to site.

- Detection limit of CO<sub>2</sub> flux system: 0.01 mg/m<sup>2</sup>/s
- The intermittence of turbulence limits the sampling error of turbulent fluxes to 10 to 20%. In addition, measurement errors must be accounted for. Fortunately, a large amount of statistical averaging reveals stable fluxes and small bias errors (< 12%) on the surface energy fluxes.

#### **10.2.3 Measurement Error for Parameters**

None given.

#### **10.2.4 Additional Quality Assessments**

None given.

#### 10.2.5 Data Verification by Data Center

Data were examined to check for spikes, values that are four standard deviations from the mean, long periods of constant values, and missing data.

#### 11. Notes

#### 11.1 Limitations of the Data

Flux data were collected during the growing season of 1994; no wintertime data were acquired.

#### 11.2 Known Problems with the Data

Data have been rejected when:

- The voltages of the  $CO_2$  and water vapor sensor were nearly or entirely off scale.
- The log book denoted problems with specific sensors.
- The gas analyzer was calibrated or when the instrument boom was moved.
- Flux runs were less than 15 minutes.
- The mean vertical velocity of the sonic anemometer exceeded 0.3 m/s (an indication of water on the transducer or continued spiking).
- Friction velocity exceeded 1.5 m/s.

Values during these periods have been assigned values of -999 (or -6999).

The third order screening of the data deleted data that were several standard deviations greater than the population means and were true spikes and outliers. The following data were deleted:

- LE fluxes greater than 350 W/m<sup>2</sup> and less than -50 W/m<sup>2</sup>.
- CO<sub>2</sub> fluxes greater than 0.50 mg/m<sup>2</sup>/s and less than -0.75 mg/m<sup>2</sup>/s.

Be careful when using data during WET periods, i.e. when the WETNESS\_SENSOR has a value of WET. These periods have not been screened and are retained to complete the record. Problems may occur because the domes on the radiometers were wet and water films may be covering optics of the IRGA and the transducer of the sonic anemometer. When using these data to test models, it is recommended that data from wet periods not be included!

Be careful about using data when wind was blowing through the tower; these data have not been deleted from the record. Closure of the surface energy balance was diminished during these periods, and an upwind bias on the vertical wind velocity, caused by aerodynamic distortion from the tower, was noted. Wind directions to be cautious about are in the zone between 350 and 60 degrees. When using these data to test models, it is recommended that data from nonideal wind directions be omitted.

Mean CO<sub>2</sub> concentrations were assigned values of 350 when the sensor was out of range. Also be cautious about using the mean CO<sub>2</sub> concentrations. There were some zero and span drifting problems with the IRGA. Typical midday CO<sub>2</sub> concentration should be on the order of 330 and 350 ppm. Data exceeding 400 ppm would have bypassed data filters and would be spurious.

The mean  $CO_2$  concentration calibrations have been double-checked and an attempt was made to compensate for drift from calibration to calibration. Sometimes the drift was small; other times it was between -10 and +10 ppm over a few days. At this point the relative change in  $CO_2$  from hour to hour is OK. Use the absolute values with much skepticism and caution. These data should not be used to assess the seasonal change in  $CO_2$  over the boreal region.

Periods when calibrating or moving boom, given as day number and ending time of the half-hour observation (Central Standard Time):

DOY	Time
143	1300
145	1130
150	1100
150	1300
151	0930
153	1030
154	0930
154	1630

```
155 1100
156 1130
161 0930
163 1030
164 0930
164 1030
164 0930
164 1000
179 1530
188 1300
189 1300
189 1330
from 200 1400 through 200 1500
201 1130
204 1230
210 1000
211 0930
215 1130
242 1500
242 1300
245 1400
from 247 1400 through 248 1000
253 1100
```

Periods when net radiometer and incident Photosynthetically Active Radiation (PAR) sensor were shaded by the tower, given as day number and ending time of the half-hour observation (Central Standard Time):

```
from 145 0800 through 145 0930 from 146 0800 through 146 0930 from 147 0800 through 147 0930 from 148 0800 through 148 0930 from 149 0800 through 149 0930 from 150 0800 through 150 0930 from 151 0800 through 151 0930
```

#### **CO<sub>2</sub> Concentration Data:**

The absolute quality of the LI-COR  $CO_2$  data is uncertain. The instrument was new to the investigator and seemed to be unstable. Calibrations were conducted almost every day, but the zero and span seemed to drift. Some first-order corrections are being made to put the values in line with reality, but more work needs to be done. The quality of these data is especially called into question because the investigator is now using a brand new sensor in Oak Ridge and automatically zeroing and spanning the sensor every day, and has not seen the zero or span change for 3 months. Spurious  $CO_2$  values may be real, however, if smoke from forest fires were a problem. Thus, there are some reservations about accepted elevated  $CO_2$  values.

#### 11.3 Usage Guidance

CAUTION should be exercised when using flux data for several hours surrounding dawn and dusk, since these are periods of unsteady conditions. In addition, nighttime data should be scrutinized.

#### 11.4 Other Relevant Information

None given.

#### 12. Application of the Data Set

These data are useful for the study of water, energy, and carbon exchange in a mature jack pine forest.

#### 13. Future Modifications and Plans

None.

#### 14. Software

#### **14.1 Software Description**

Some samples of code used in the analysis are shown in Section 9.1.1.

#### 14.2 Software Access

None given.

#### 15. Data Access

The TF-05 SSA-OJP tower flux and meteorological data are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

#### 15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services Oak Ridge National Laboratory P.O. Box 2008 MS-6407 Oak Ridge, TN 37831-6407 Phone: (423) 241-3952

Fax: (423) 574-4665

E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

#### 15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

#### 15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

#### 15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

#### 16. Output Products and Availability

#### **16.1 Tape Products**

None.

#### 16.2 Film Products

None.

#### 16.3 Other Products

These data are available on the BOREAS CD-ROM series.

#### 17. References

### 17.1 Platform/Sensor/Instrument/Data Processing Documentation None.

#### 17.2 Journal Articles and Study Reports

Amiro, B.D. 1990. Comparison of turbulence statistics within three boreal forest canopies. Boundary Layer Meteorology. 51:00-121.

Auble, D.L. and T.P. Meyers. 1992. An open path, fast response infrared-absorption gas analyzer for H<sub>2</sub>O and CO<sub>2</sub>. Boundary Layer Meteorology. 59:243-256.

Baldocchi, D.D. and C.A. Vogel. 1995. Energy and CO<sub>2</sub> flux densities above and below a temperate broad-leaved forest and boreal pine forest. Tree Physiology, Volume 16, March 1995, pp. 5-16.

Baldocchi, D.D. and T.P. Meyers. 1991. Trace gas exchange above the floor of a deciduous forest. 1: Evaporation and  $CO_2$  efflux. J. Geophys. Res. 96:7271-7285.

Baldocchi, D.D., B.B. Hicks, and T.P. Meyers. 1988. Measuring biosphere-atmosphere exchanges of biologically related gases with micrometeorological methods. Ecology, 69:1331-1340.

Baldocchi, D.D., C.A. Vogel, and B. Hall. 1997. Seasonal variation of carbon dioxide exchange rates above and below a boreal jack pine forest. Agricultural and Forest Meteorology 83: 147-170.

Baldocchi, D.D., C.A. Vogel, and B. Hall. 1997. Seasonal variation of energy and water vapor exchange rates above and below a boreal jack pine forest canopy. Journal of Geophysical Research 102(D24): 28,939-28,951.

Baldocchi DD, S.B. Verma, and D.E. Anderson DE. 1987. Canopy photosynthesis and water-use efficiency in a deciduous forest. Journal of Applied Ecology 24: (1) 251-260. Businger, J.A. 1986. Evaluation of the accuracy with which dry deposition can be measured with current micrometeorological techniques. J. Clim. and Appl. Meteorol. 25:1100-1124.

Kaimal, J.C. and J.E. Gaynor. 1991. Another look at sonic thermometry. Boundary Layer Meteorology. 56:401-410.

Kaimal, J.C., J.E. Gaynor, H.A. Zimmerman, and G.A. Zimmerman. 1990. Minimizing flow distortion errors in a sonic anemometer. Boundary Layer Meteorology. 53:103-115.

Mcmillen, R.T. 1988. An eddy-correlation technique with extended applicability to non-simple terrain. Boundary-Layer Meteorology 43: (3) 231-245.

Monteith, J.L. and M.H. Unsworth. 1990. Principles of Environmental Physics. Edward Arnold, London.

Moore, C.J. 1986. Frequency response corrections for eddy correlation measurements. Boundary Layer Meteorology. 37:17-35.

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. 2000. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM.

Schotanus, P., F.T.M. Nieuwstadt, and H.A.R. De Bruin. 1983. Temperature measurement with a sonic anemometer and its application to heat and moisture fluxes. Boundary Layer Meteorology. 26: 81-93.

Sellers, P. and F. Hall. 1994. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1994-3.0, NASA BOREAS Report (EXPLAN 94).

Sellers, P. and F. Hall. 1996. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1996-2.0, NASA BOREAS Report (EXPLAN 96).

Sellers, P., F. Hall, and K.F. Huemmrich. 1996. Boreal Ecosystem-Atmosphere Study: 1994 Operations. NASA BOREAS Report (OPS DOC 94).

Sellers, P., F. Hall, and K.F. Huemmrich. 1997. Boreal Ecosystem-Atmosphere Study: 1996 Operations. NASA BOREAS Report (OPS DOC 96).

Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. den Hartog, J. Cihlar, M.G. Ryan, B. Goodison, P. Crill, K.J. Ranson, D. Lettenmaier, and D.E. Wickland. 1995. The boreal ecosystem-atmosphere study (BOREAS): an overview and early results from the 1994 field year. Bulletin of the American Meteorological Society. 76(9):1549-1577.

Sellers, P.J., F.G. Hall, R.D. Kelly, A. Black, D. Baldocchi, J. Berry, M. Ryan, K.J. Ranson, P.M. Crill, D.P. Lettenmaier, H. Margolis, J. Cihlar, J. Newcomer, D. Fitzjarrald, P.G. Jarvis, S.T. Gower, D. Halliwell, D. Williams, B. Goodison, D.E. Wickland, and F.E. Guertin. 1997. BOREAS in 1997: Experiment Overview, Scientific Results and Future Directions. Journal of Geophysical Research 102(D24): 28,731-28,770.

Verma, S.B., D.D. Baldocchi, D.E. Anderson, D.R. Matt, and R.J. Clement. 1986. Eddy fluxes of CO<sub>2</sub>, water vapor, and sensible heat over a deciduous forest. Boundary-Layer Meteorology 36: 71-91.

Wesely, M.L., D.H. Lenschow, and O.T. Denmead. 1989. Flux measurement techniques. In: Global Tropospheric Chemistry - Chemical Fluxes in the Global Atmosphere. D.H. Lenschow and B.B. Hicks (eds.). Report of the Workshop on the Measurements of Surface Exchange and Flux Divergence of Chemical Species in the Global Atmosphere. pp. 31-46. Prepared by the National Center for Atmospheric Research, Boulder, CO. 107 pp.

## **17.3** Archive/DBMS Usage Documentation None.

#### 18. Glossary of Terms

None.

#### 19. List of Acronyms

A/D - Analog-to-Digital
AES - Atmospheric Environment Service AFM - Airborne Fluxes and Meteorology

ASCII - American Standard Code for Information Interchange

ATDD - Atmospheric Turbulence and Diffusion Division

ATI - Applied Technology, Inc.

BOREAS - BOReal Ecosystem-Atmosphere Study

BORIS - BOREAS Information System CD-ROM - Compact Disk-Read-Only Memory - Distributed Active Archive Center DAAC

EOS - Earth Observing System

EOSDIS - EOS Data and Information System GIS - Geographic Information System

- Greenwich Mean Time GMT

GSFC - Goddard Space Flight Center HTML - HyperText Markup Language IFC - Intensive Field Campaign
IRGA - Infrared Gas Analyzer

NAD83 - North American Datum of 1983

NASA - National Aeronautics and Space Administration NOAA - National Oceanic and Atmospheric Administration

NSA - Northern Study Area OJP - Old Jack Pine

ORNL - Oak Ridge National Laboratory PANP - Prince Albert National Park

PAR - Photosynthetically Active Radiation PPFD - Photosynthetic Photon Flux Density REBS - Radiation Energy Balance Systems

SSA - Southern Study Area
TE - Terrestrial Ecology

- Tower Flux TF

URL - Uniform Resource Locator

OMW - World Meteorological Organization

#### 20. Document Information

#### 20.1 Document Revision Date

Written: 05-Mar-1996 Revised: 30-Jul-1999

#### 20.2 Document Review Date(s)

BORIS Review: 20-MAY-1998 Science Review: 04-AUG-1998

#### 20.3 Document ID

None.

#### 20.4 Citation

When using these data, please include the following acknowledgment as well as citations of relevant papers in Section 17.2:

Scalar and energy flux data (e.g., CO<sub>2</sub>, water vapor, sensible heat, and solar energy):

Coauthorship if there is extensive use of the data. Acknowledgment if a few data are used to make a supporting point.

#### Meteorological data:

Acknowledgment: Field data obtained and prepared by Dennis Baldocchi and Christoph Vogel. Atmospheric Turbulence and Diffusion Division, NOAA P.O. Box 2456, Oak Ridge, TN 37831

If using data from the BOREAS CD-ROM series, also reference the data as:

Baldocchi, D. and C. Vogel, "Experimental and Modeling Studies of Water Vapor, Sensible Heat, and CO<sub>2</sub> Exchange Over and Under a Boreal Forest." In Collected Data of The Boreal Ecosystem-Atmosphere Study. Eds. J. Newcomer, D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers. CD-ROM. NASA, 2000.

#### Also, cite the BOREAS CD-ROM set as:

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM. NASA, 2000.

#### 20.5 Document Curator

#### 20.6 Document URL

#### REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson

Davis Highway, Suite 1204, Arlington, VA 22202-43			
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE October 2000	3. REPORT TYPE AN Technical Me	
4. TITLE AND SUBTITLE			5. FUNDING NUMBERS
Technical Report Series on the Bo	oreal Ecosystem-Atmosphe	re Study (BOREAS)	
BOREAS TF-5 SSA-OJP Tov	wer Flux and Meteorolog	gical Data	923
6. AUTHOR(S)	•		RTOP: 923-462-33-01
` '	anh Vagal		
Dennis Baldocchi and Christo			
Forrest G. Hall and Karl Hue	mmrich, Editors		
7. PERFORMING ORGANIZATION NAMI	E(S) AND ADDRESS (ES)		8. PEFORMING ORGANIZATION REPORT NUMBER
Goddard Space Flight Center			REPORT NOWIBER
Greenbelt, Maryland 20771			2000-03136-0
Greensen, maryiana 20771			
9. SPONSORING / MONITORING AGE	ENCY NAME(S) AND ADDRES	SS (ES)	10. SPONSORING / MONITORING AGENCY REPORT NUMBER
National Aeronautics and Space	Administration		TM-2000-209891
Washington, DC 20546-0001	7 Idillimotiation		Vol. 200
, usinington, 2 c 2 cc 10 0001			VOI. 200
11. SUPPLEMENTARY NOTES			
D. Baldocchi & C. Vogel: Na	tional Oceanic and Atmo	ospheric Administra	ation/ATDD, Oakridge, Tenn.;
K. Huemmrich: Univ. of Mar	yland, NASA Goddard S	Space Flight Center	Greenbelt, Maryland
12a. DISTRIBUTION / AVAILABILITY STA	TEMENT		12b. DISTRIBUTION CODE
Unclassified–Unlimited			125. 51611(1561161( 6652
Subject Category: 43			
Report available from the NASA	A Center for AeroSpace In	formation	
7121 Standard Drive, Hanover,	•		
·	21070-1320. (301) 0	21-0370.	
13. ABSTRACT (Maximum 200 words)			
			-OJP site through the growing
season of 1994. The data are	available in tabular ASC	CII files.	
14 SUBJECT TERMS			15 NUMBER OF PAGES

17. SECURITY CLASSIFICATION OF REPORT OF THIS PAGE Unclassified Unclassified

18. SECURITY CLASSIFICATION

19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified

20. LIMITATION OF ABSTRACT

26

16. PRICE CODE

BOREAS, tower flux.